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DECREASING DEMAND ON EXISTING SYSTEMS

4.0 INTRODUCTION

The design seismic forces (or demand forces) prescribed by most building codes generally are proportional to building weight and inversely proportional to the two-thirds power of the fundamental period of vibration of the building and to a response reduction factor that represents the capability of the structural system to absorb energy in the inelastic range of the building response. Within this context, the earthquake demand of a building may be reduced by reducing the weight of the building, increasing the fundamental period and the energy dissipating capacity of the structural system, or using alternate procedures.

4.1 REDUCING THE WEIGHT OF THE BUILDING*

In relatively low buildings (i.e., below 3 to 5 stories), reducing the weight of the building will result in a reduction of the seismic forces on the structural elements. Although a reduction in weight will decrease the fundamental period of vibration, the code-prescribed seismic force coefficient remains constant (i.e., is not affected by a change in fundamental period) for these buildings, so the reduction in the seismic forces is directly proportional to the weight reduction.

For taller buildings (i.e., 6 to 10 stories), the reduction in the fundamental period resulting from a reduction in weight (i.e., the period is proportional to the square root of the weight) also will result in an increase in the seismic force coefficient. This increase will tend to offset the decrease associated with the reduction in weight. For very tall buildings (i.e., 20 stories or more), the effect of the fundamental period is minimal and the seismic forces are essentially proportional to the reduced weight.

Techniques. Techniques that have been utilized to reduce weight include:

1. Removing the upper stories of a building.

2. Changing the use of the building (e.g., converting from heavy warehouse loading to office or residential use).

3. Removing a heavy roof system and replacing it with a lighter assembly.

4. Removing heavy appurtenances (i.e., parapets, balconies, water towers, or equipment).

Relative Merits. Removal of the upper stories is an effective technique for decreasing the earthquake demand on a building. As indicated above, this technique may be less effective for buildings of moderate height than it is for low or very tall buildings. An additional benefit associated with this technique is the reduction in gravity loads. Use of this technique will result in reduced forces on the existing vertical-load-resisting elements in the remaining stories and foundations thereby providing additional capacity for seismic forces. The primary disadvantage of this technique is the loss of usable space and the associated loss of rental income and resale value.

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*The American Iron and Steel Institute has written a minority opinion concerning this section; see page 193.

Changing the use of the building in order to eliminate heavy floor loads that contribute to the seismic force also is an effective technique to reduce the seismic demand. Since the ground floor and its tributary loads do not contribute to the building seismic forces, reducing the floor loads in the upper floors of a multi story building is most effective. This technique also reduces the forces on the vertical-load-resisting elements and, thus, increases the capacity of these elements for seismic forces. The elimination of heavy floor loads that are regarded as dead loads in seismic provisions will affect the fundamental period of the building in a manner similar to that discussed above for the removal of upper stories. Also as discussed above, the advantage of weight reduction may be partly offset for moderate height buildings by an increase in the seismic force level due to the period changes. An additional factor to be considered for this technique is whether the change in use or occupancy will trigger other building code requirements (e.g., fire protection, egress) that may be costly to meet.

Removal and replacement of a heavy roof system is particularly effective in reducing the seismic demands on an existing one-story building. As the number of stories is increased, this technique becomes less effective and it is also subject to the limitations for moderate height buildings discussed above.

Removal of heavy appurtenances has the same effects on seismic demand as discussed above for the removal of stories or the elimination of heavy floor loads.

4.2 INCREASING THE FUNDAMENTAL PERIOD AND THE ENERGY DISSIPATING CAPACITY OF THE STRUCTURAL SYSTEM

By increasing the fundamental period of vibration of some structures, the seismic demand can be decreased. The most effective method for increasing the fundamental period of the building system without modification of the structural system of the building is by introduction of seismic isolators at the base of the building. The seismic isolators can increase the effective fundamental period of the system, thus reducing the base shear of the structural system of the building; energy dissipation also can be included within the isolator system.

In addition to seismic isolation, energy dissipation devices may be added to the structural system. The energy dissipation system increases the system damping and modifies the building response and provides the equivalent of increasing the value of the response modification factor, R.

Techniques. The response reduction factor (i.e., energy dissipating capacity) applicable to an existing building can be increased by:

1. Modifying the existing structural systems,

2. Supplementing the existing structural systems, or

3. Replacing the existing structural systems.

Relative Merits. Modification of an existing structural system to improve its energy absorbing capacity is seldom feasible except in the case of an ordinary steel moment frame. In this case, it may be possible to upgrade the frame to a special moment frame or to the minimum frame requirements for a dual system in conjunction with existing shear walls. Similarly, removal and replacement of an existing structural system seldom will be economically feasible unless dictated by other than engineering considerations (e.g., complete architectural retrofit of the exterior of the building). A possible exception to this statement could occur in existing steel frame buildings with concentric steel bracing or unreinforced masonry infill walls. In these cases, it may be feasible to remove the bracing or the infill walls and install eccentric bracing or reinforced concrete shear walls. Supplementing the existing structural system is, by far, the most common technique for seismic strengthening and, in many cases, it is possible to reduce the seismic demand by improving the energy absorption characteristics of the combined system.

4.3 ALTERNATE PROCEDURES

The *NEHRP Recommended Provisions* as well as model building codes provide for approval of alternative procedures that can be demonstrated to be equivalent to code-prescribed procedures concerning strength, durability, and seismic resistance. In recent years, several innovative alternative procedures for the reduction of seismic demand have been subjected to analytical and experimental research and have seen limited application in both new and existing buildings. These procedures include:

- Seismic isolation techniques and
- Supplemental damping techniques.

4.3.1 SEISMIC ISOLATION

Techniques. Base isolation is a generic term for procedures whereby the response characteristics of a building are altered by the introduction of devices or special construction at the base of the building. The discussion here is confined to the use of base isolation to reduce seismic demand by lengthening the fundamental period of vibration of an existing building.

Relative Merits. Most base isolation devices are capable of developing a fundamental period of about 2 seconds. This can effectively reduce the seismic demand for buildings founded on rock or firm soils that have a natural fundamental period of about 1 second or less (i.e., buildings less than about 10 stories). Base isolation may be detrimental to buildings founded on very soft soils where a 2 second period base-isolated building may be in resonance with similar periods in the ground motion transmitted by the soft soils.

Implementation of base isolation for existing buildings usually will require that the building be underpinned for the installation of base isolation pads. A competent diaphragm also is required above the isolation pads to distribute the lateral forces and, for existing buildings, a new concrete slab generally has been provided to serve this purpose. Finally, provision must be made to accommodate the large displacement of the isolation pad; this usually is done by providing both adequate clearance around the building to accommodate this displacement and sliding or flexible connections for all utilities and services to the building.

4.3.2 SUPPLEMENTAL DAMPING

Techniques. Structural damping may be defined as an internal energy absorption characteristic of a structural system that acts to attenuate induced free vibration. Damping is commonly expressed as a percentage of critical damping. A zero damped elastic system, when displaced, theoretically would vibrate continuously at its natural period and at the same amplitude. A critically damped structure when displaced would return to its original position without vibration. Damping also tends to reduce the dynamic amplification of vibration particularly when the period of the building is in resonance with the ground motion. The seismic provisions in most building codes are based on 5 percent of critical damping as being representative of most building structures. The upper limit of the required seismic forces, before division by the response reduction factor, assumes dynamic amplification of the ground motion by a factor of 2 to 2.5 depending on the soil conditions. If the structure can develop 20 percent damping, the above amplification (and the displacements) would be reduced by one-half. The various concepts that have been proposed for providing supplementary damping are:

- Viscous damping,
- Friction damping, and
- Natural yield damping.

Viscous damping involves taking advantage of the high flow resistance of viscous fluids. A simple shock absorber like that on an automobile is one example. Other devices such as a pair of flat plates with viscous fluid between them have been proposed. Shock absorbers have been implemented in connection with nuclear power plant piping systems but they have proved to be very high maintenance cost items.

Friction between dry surfaces produces a constant force, always opposed to the direction of motion, that is proportional to the contact force between the surfaces and the coefficient of friction of the materials. A number of friction damping devices usually associated with diagonal bracing in buildings, have been proposed. Major concerns with friction dampers in connection with the long-term periods between earthquakes are ensuring that the contact forces between the sliding surfaces do not change and ensuring that the coefficient of friction does not change.

Natural yield damping of structural elements in buildings (e.g., beams) has long been recognized as providing added damping to structures. Material yielding is very commonly used in earthquake engineering in conjunction with the ductility, seismic isolation, and supplemental damping concepts of design. In recent years, a variety of mechanical devices that incorporate the yielding deformation of mild steel to provide supplemental damping have been implemented in earthquake-resistant designs of buildings and other structures. Mild steel bars in torsion and cantilevers in flexure have been developed, tested, and installed in buildings and bridges. Similarly, lead shear and lead extrusion devices also have been developed.

Relative Merits. The application of supplemental damping in the seismic rehabilitation of existing buildings is in its infancy; hence, the benefits and problems of the various alternatives have not been thoroughly investigated. In general, devices that involve material yielding as the means for increasing energy dissipation or damping can be regarded as being very reliable. Mild steel and lead are very stable materials with predictable yield deformation characteristics.

Irrespective of the type of damping involved, the installation in buildings of devices commonly proposed thus far in connection with supplemental damping involves distributing the devices throughout a structure. The seismic response of a damped building would be similar to that of a conventional building. This is in contrast to the seismic isolation concept where virtually all of the relative displacement occurs at the isolation level.

Change in period of vibration and stiffness associated with material yield damping can be significant depending on the ground motion demand and the elastic strength of the damper. Practical supplemental damping devices that involve material yielding generally result in a reduction of stiffness during earthquake response and, thus, periods lengthen. Although the change in period may be of little importance, the change may result in decreased demand forces. The seismic analysis of buildings using supplemental dampers requires sophisticated nonlinear time-history analytical tools because of the yielding (i.e., inelastic) response requirements.